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FINITE ELEMENT ANALYSIS OF THERMAL BARRIER COATINGS

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The near-term objective of this investigation is to develop an understanding of the states of stresses and strains in a Zirconia-yttria thermal barrier coating (TBC) experiencing a given temperature drop. Results so obtained are expected to facilitate experimental work. In order to gain realistic insights into the distribution of stresses and strains in a complex TBC, the finite element approach was selected to model a cylindrical TBC specimen. Experimental evidence reported in the literature indicated the presence of (near-sinusoidal) rough interface between the ceramic coat and the bond coat. Oxidation of the bond coat at ceramic-bond interface was observed, as was a small amount of cracking in the ceramics near the ceramic-bond interface. To account for these complex features, a plane-strain finite element computer program known as TBCOC has been developed, taking advantage of a generic computer code known as MARC. This generic code has been made available to this co-operative research effort through the use of a supercomputer (Cray I) at NASA Lewis Research Center. The TBCOC model contains 1316 nodal points and 2140 finite elements. It is capable of a uniform isothermal loading. Results of a sample computer run are presented. The loading for this run is a 180°F (100°C) drop from 1292°F (700°C). Material properties used are best estimates for 1292°F, based largely on experimental/commercial data as well as those used in the literature. These results have been favorably correlated with runs using a less sophisticated finite element model (the Basic TBC) in mid-1984. Stress build-ups (in shearing, radial, and to a lesser extent, hoop stresses) in the vicinity of the sinusoidal ceramic-bond interface have been observed. The greatest tensile stress concentration occurs in the ceramic layer in the immediate vicinity of the peaks of the sinusoidal interface. This tensile build-up nearly coincides with cracks observed in experimental work reported by other investigators in recent years.

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TABLE I. - MATERIAL PROPERTIES

	E (psi)	μ	ρ (pci)	α (in./in./°F)
Ceramic	4×10^6	0.25	0.204	5.56×10^{-6}
Bond Coat	20×10^6	0.27	0.252	8.42×10^{-6}
Substrate	25.5×10^6	0.25	0.280	7.73×10^{-6}

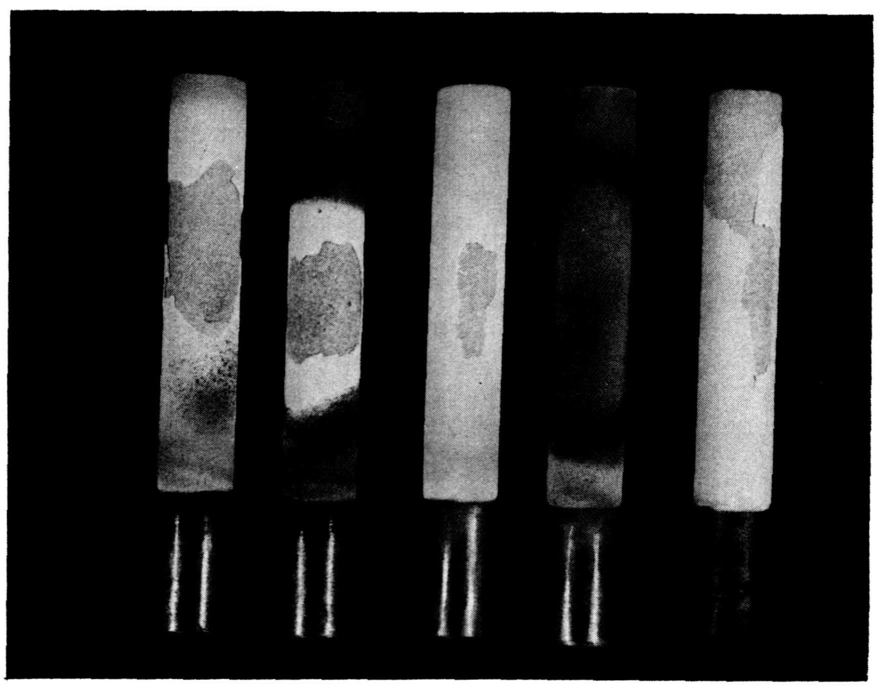

Figure 1. Cylindrical Specimens with Spalled Thermal Barrier Coatings

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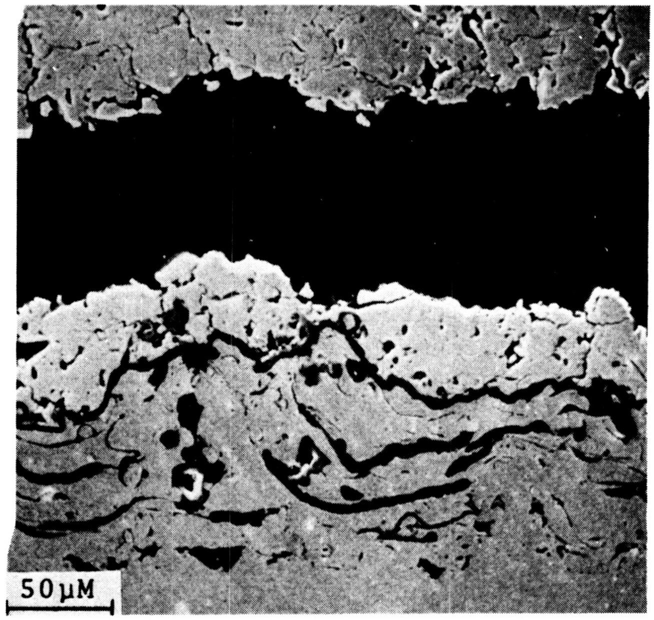


Figure 2. SEM Photomicrograph of the Cross Section of a Thermal Barrier Coating System. (Specimen has failed (delaminated) but not yet spalled.)

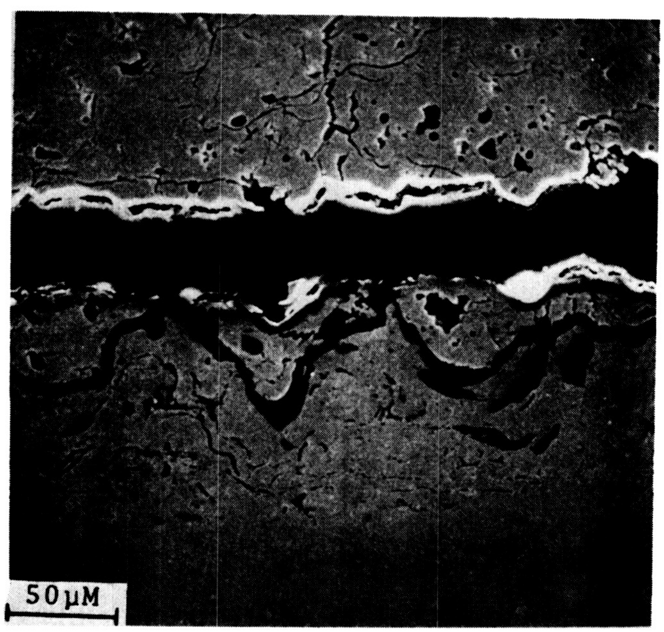


Figure 3. SEM Photomicrograph of the Cross Section of a Thermal Barrier Coating System. (Specimen has failed (delaminated) on cooling. Spalling would occur on subsequent heat up.)

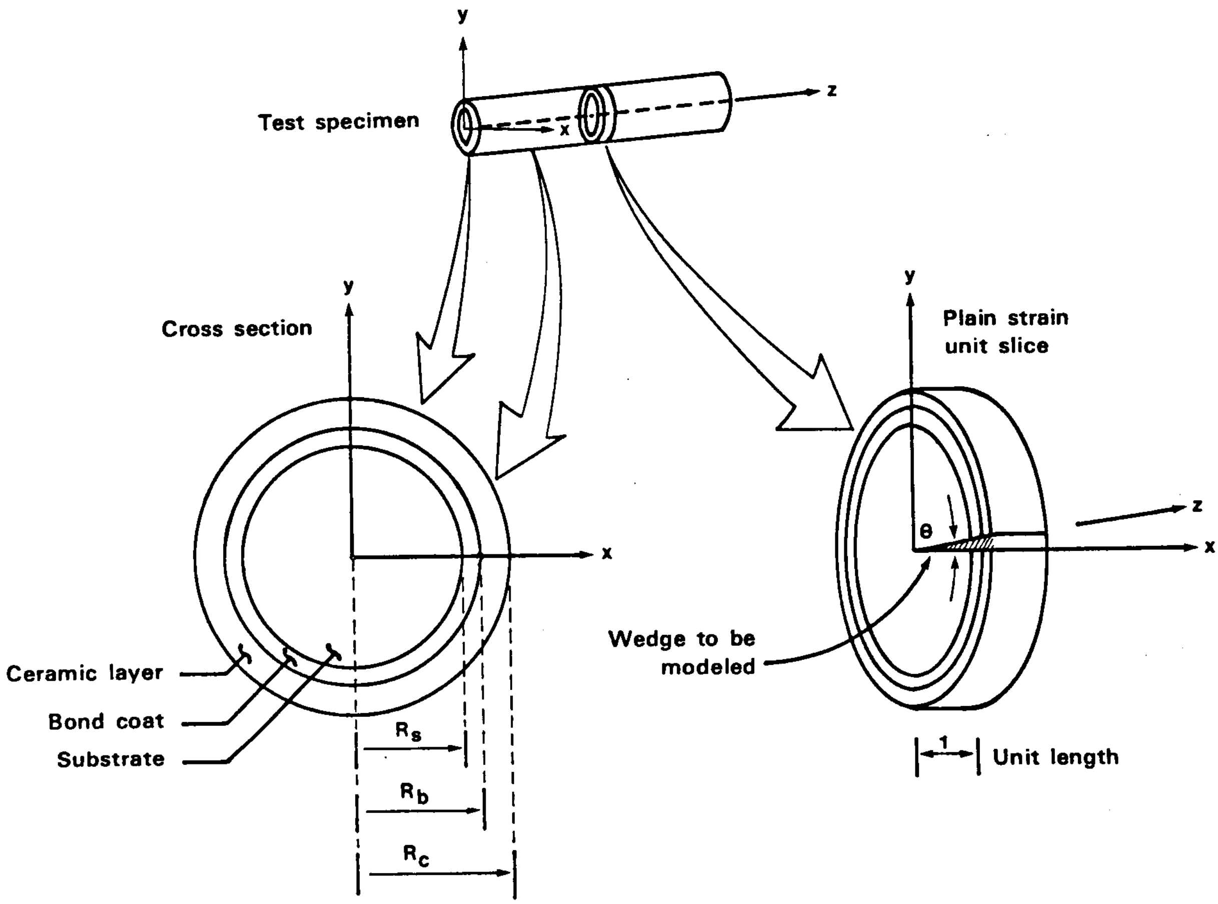


FIGURE 4. CYLINDRICAL TBC TEST SPECIMEN

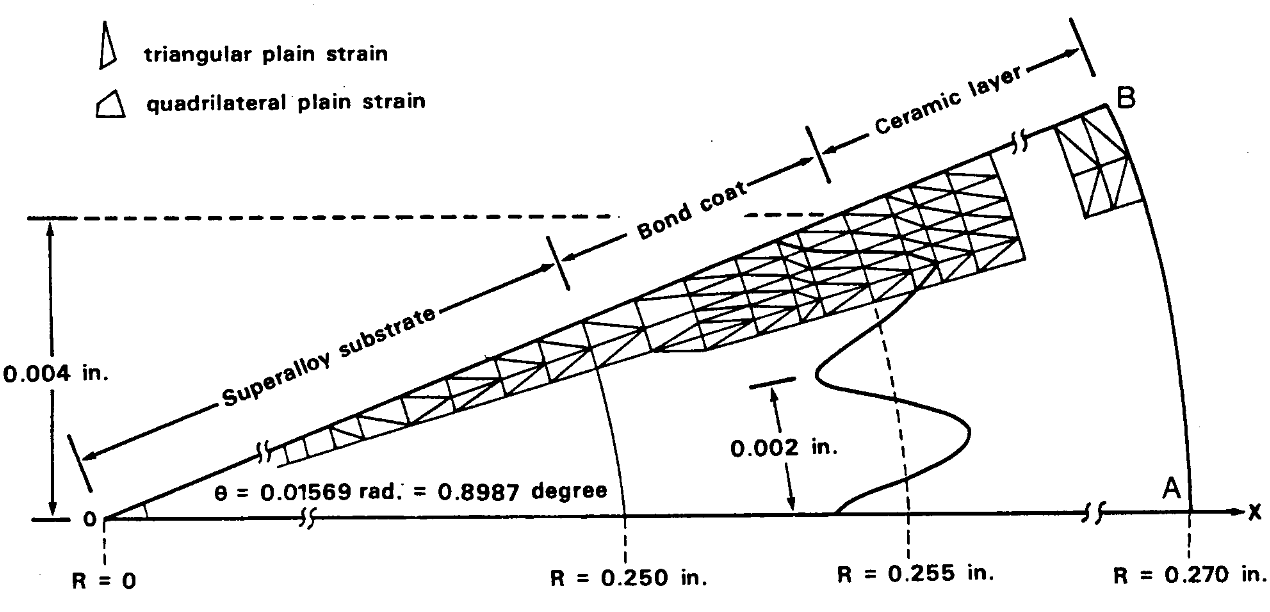
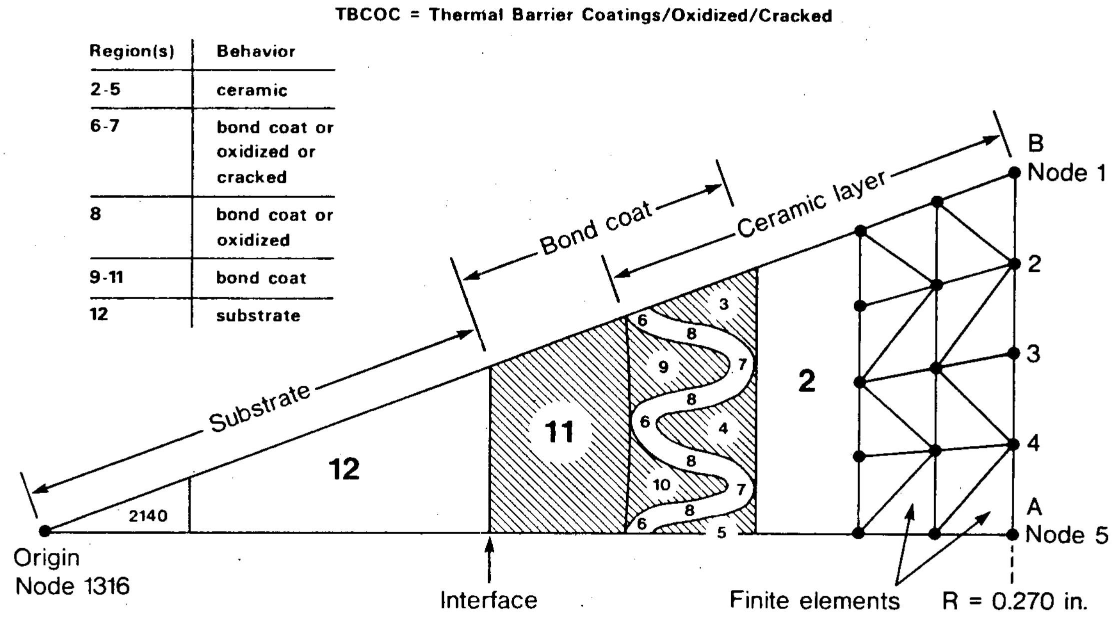


FIGURE 5. THE BASIC TBC FINITE ELEMENT MODEL



Region(s)	Behavior
2-5	ceramic
6-7	bond coat or oxidized or cracked
8	bond coat or oxidized
9-11	bond coat
12	substrate

FIGURE 6. OVERVIEW OF THE ADVANCED TBCOC MODEL

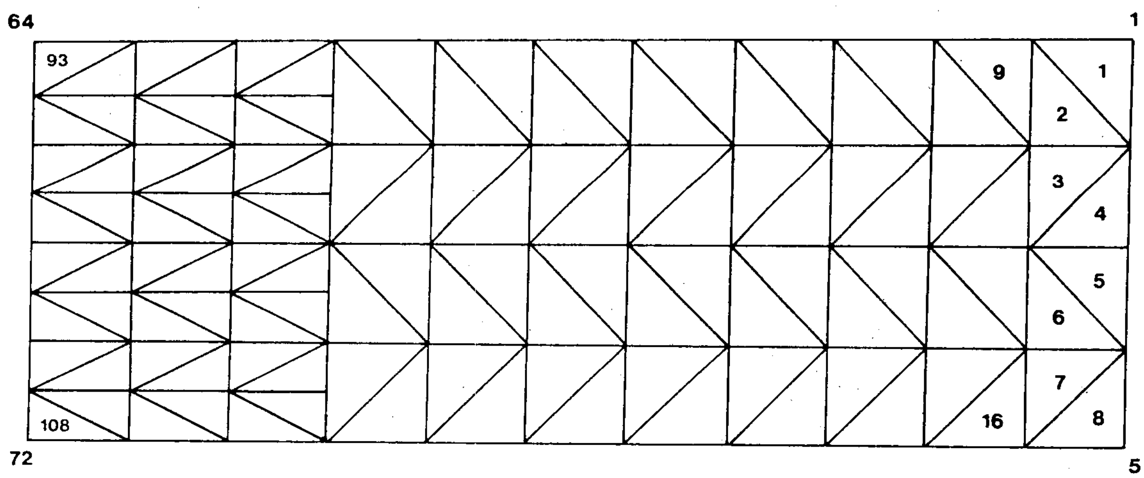


FIGURE 7. TBCOC MODEL (PART 1)

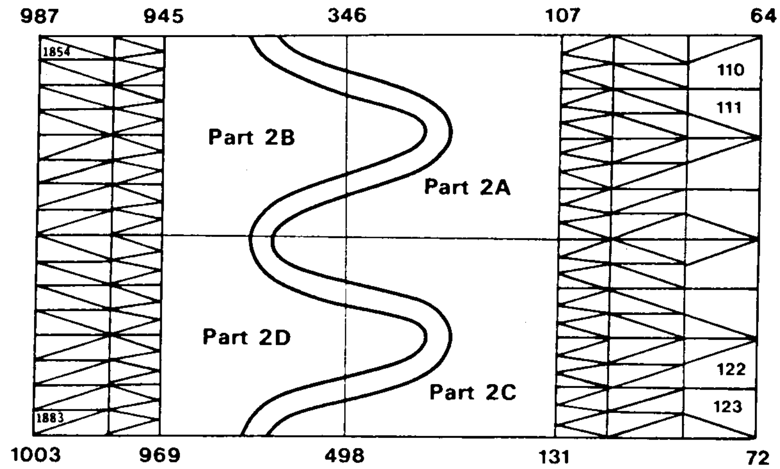


FIGURE 8. TBCOC MODEL (PART 2)

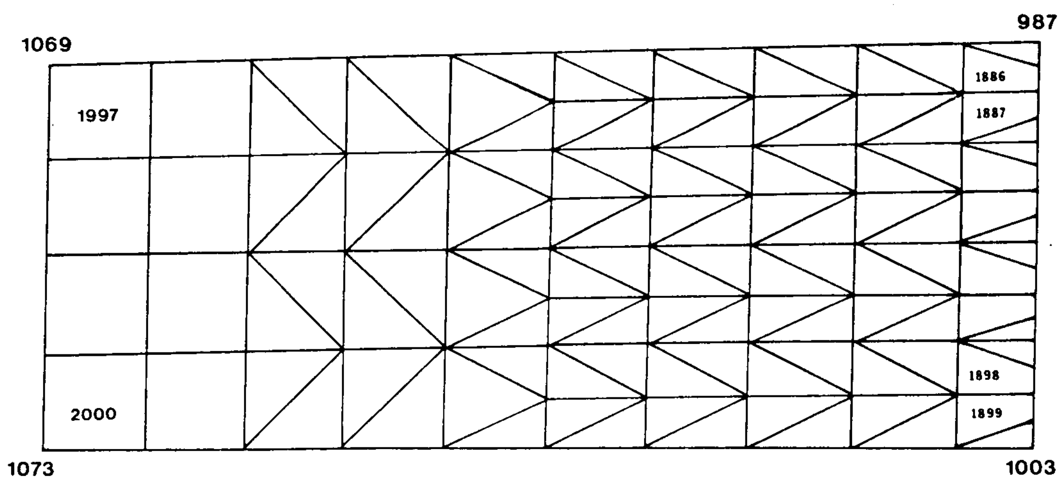


FIGURE 9. TBCOC MODEL (PART 3)

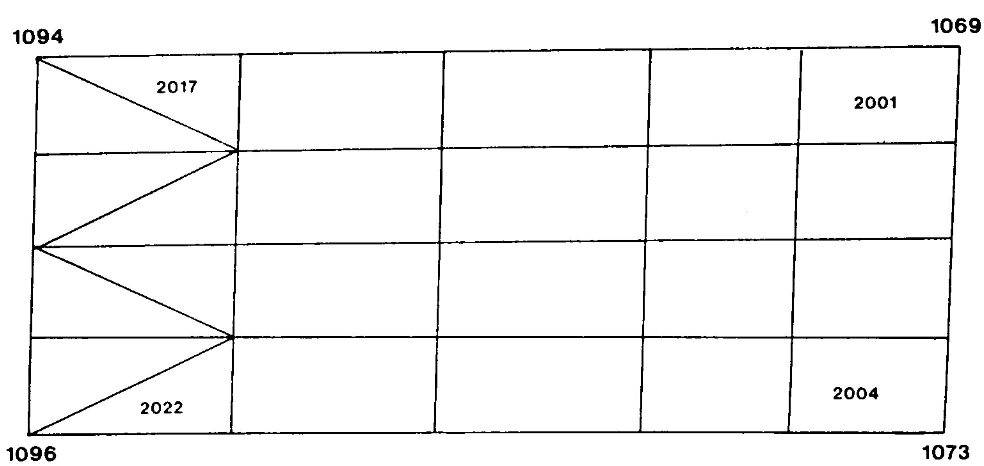


FIGURE 10. TBCOC MODEL (PART 4)

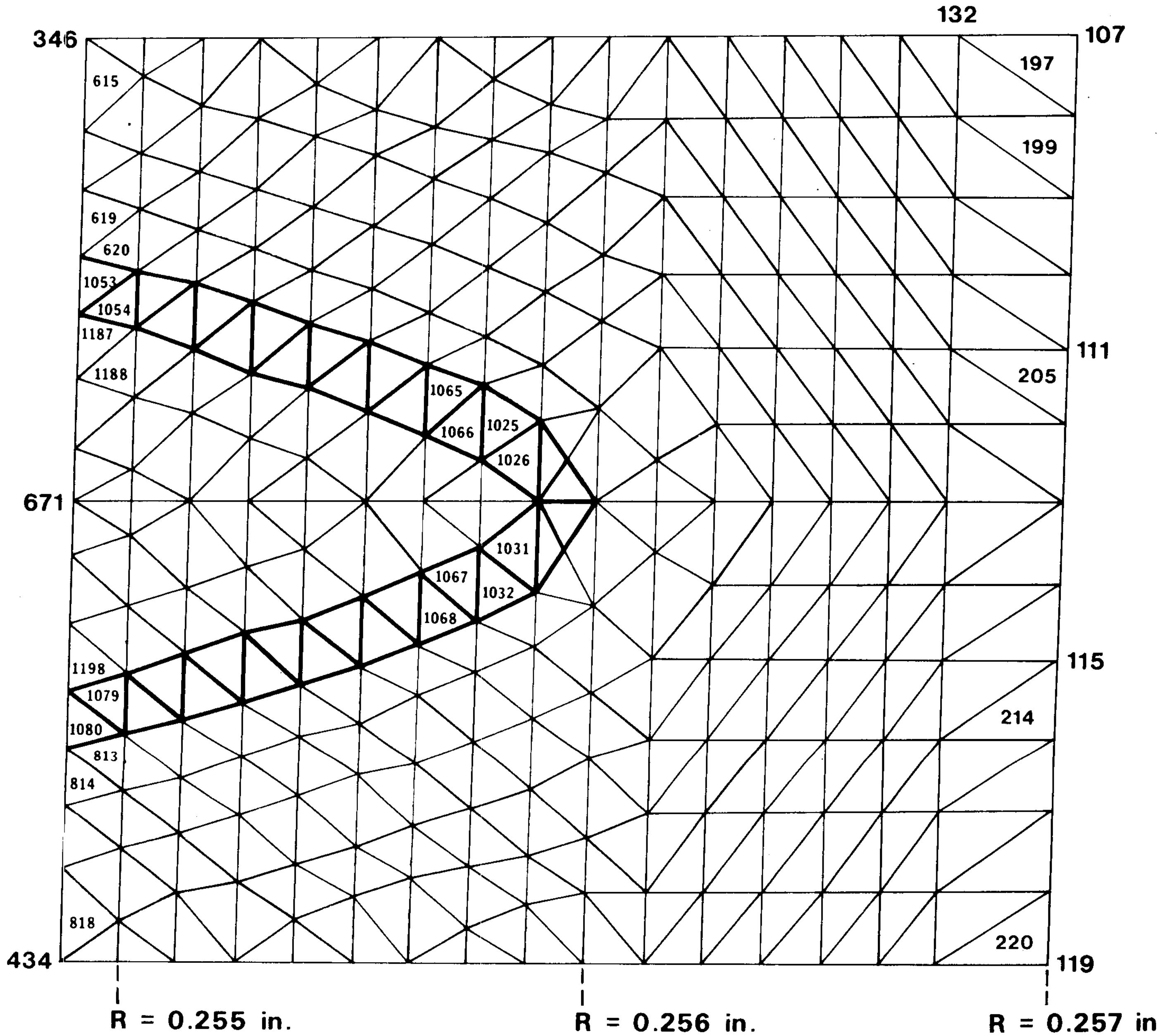


FIGURE 11. FINITE ELEMENT DETAILS (PART 2A)

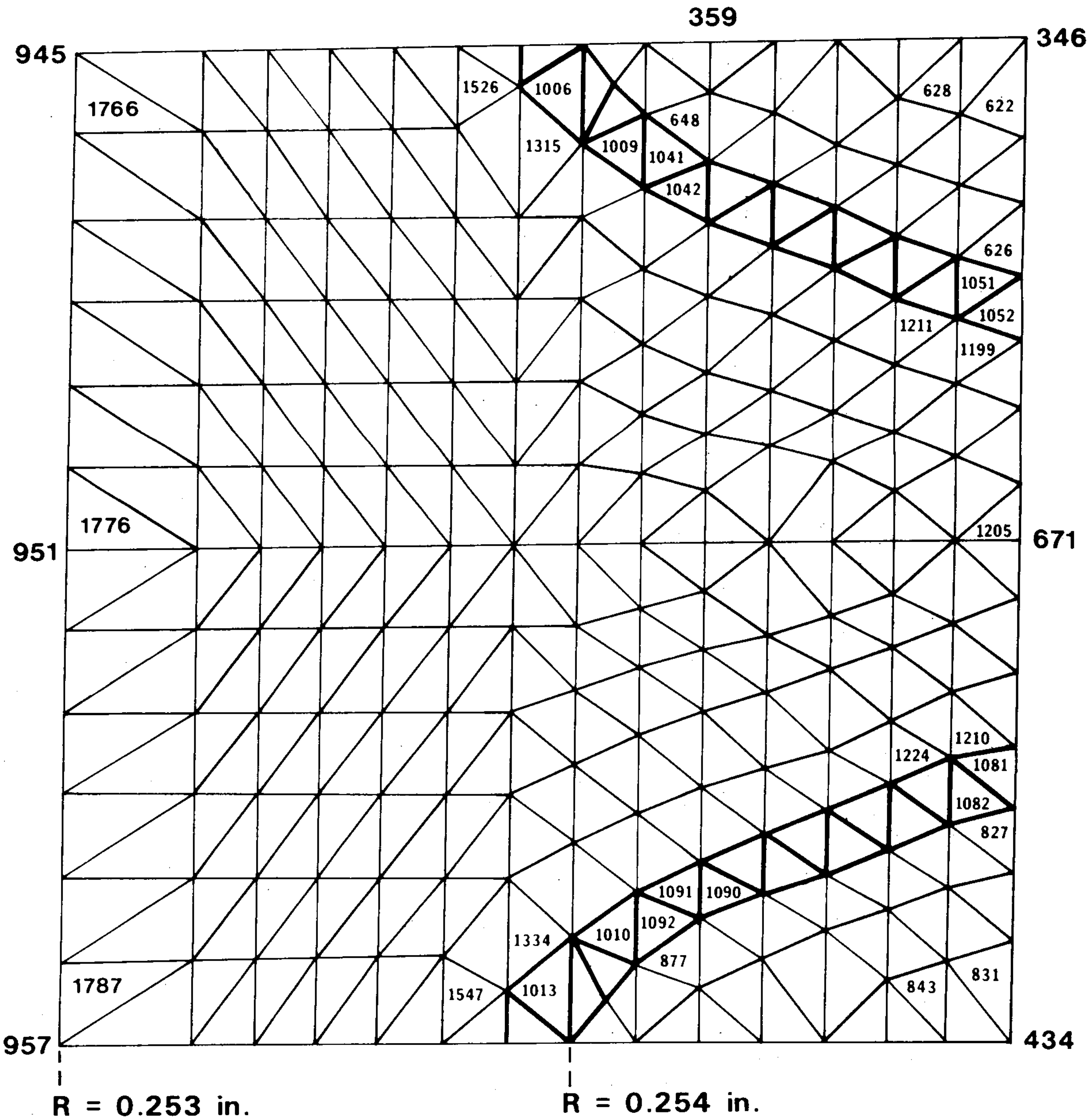


FIGURE 12. FINITE ELEMENT DETAILS (PART 2B)

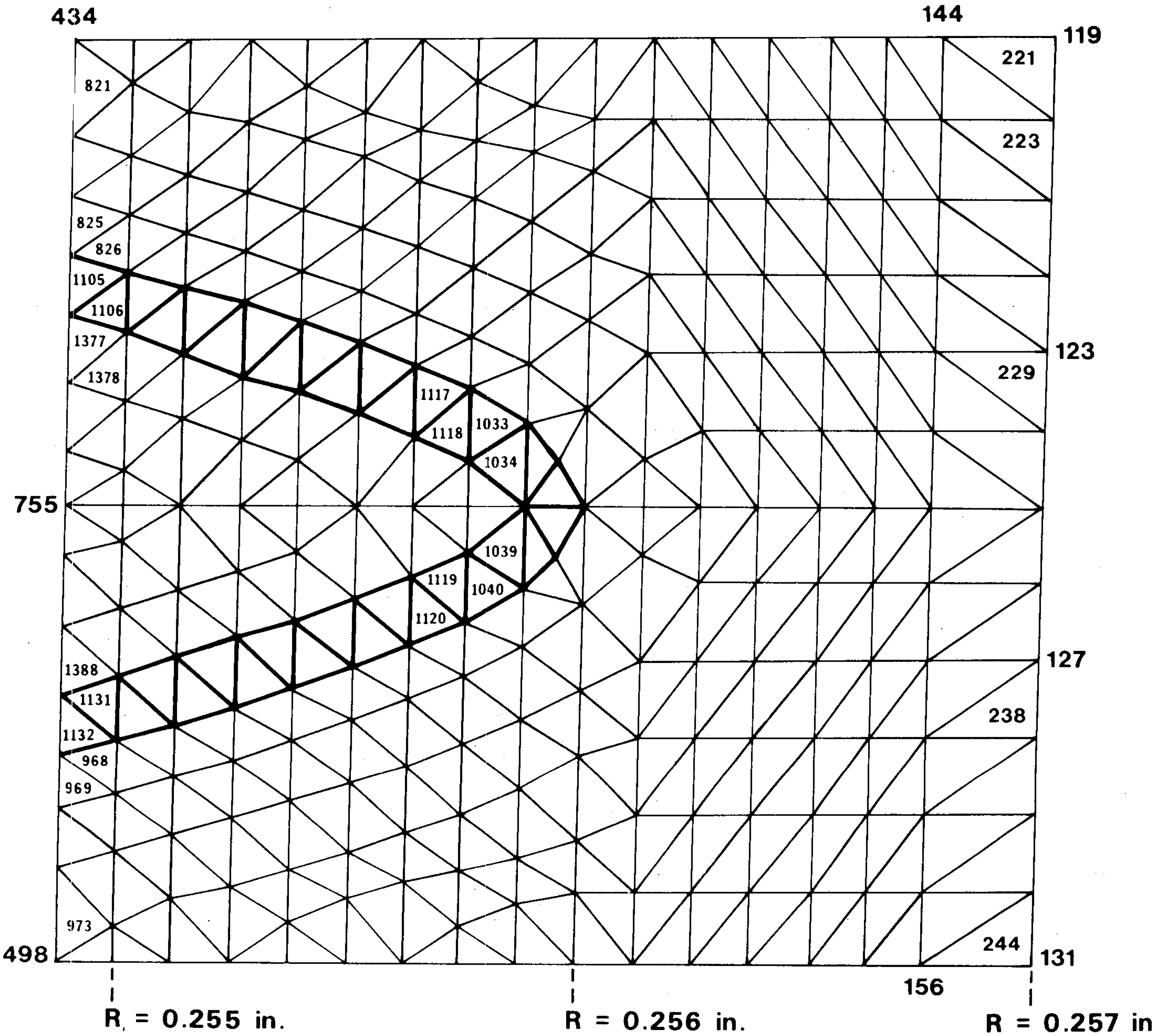


FIGURE 13. FINITE ELEMENT DETAILS (PART 2C)

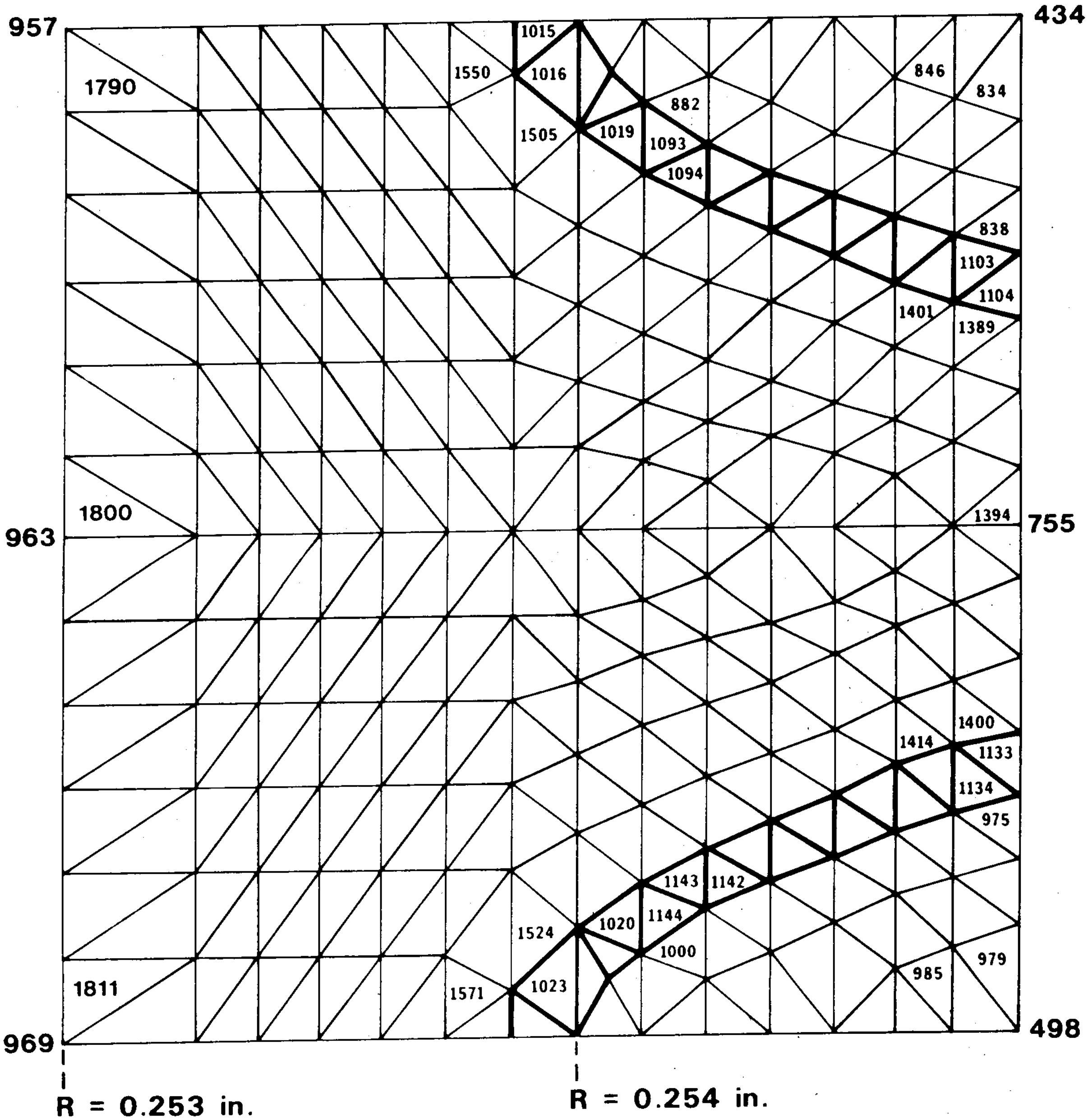


FIGURE 14. FINITE ELEMENT DETAILS (PART 2D)

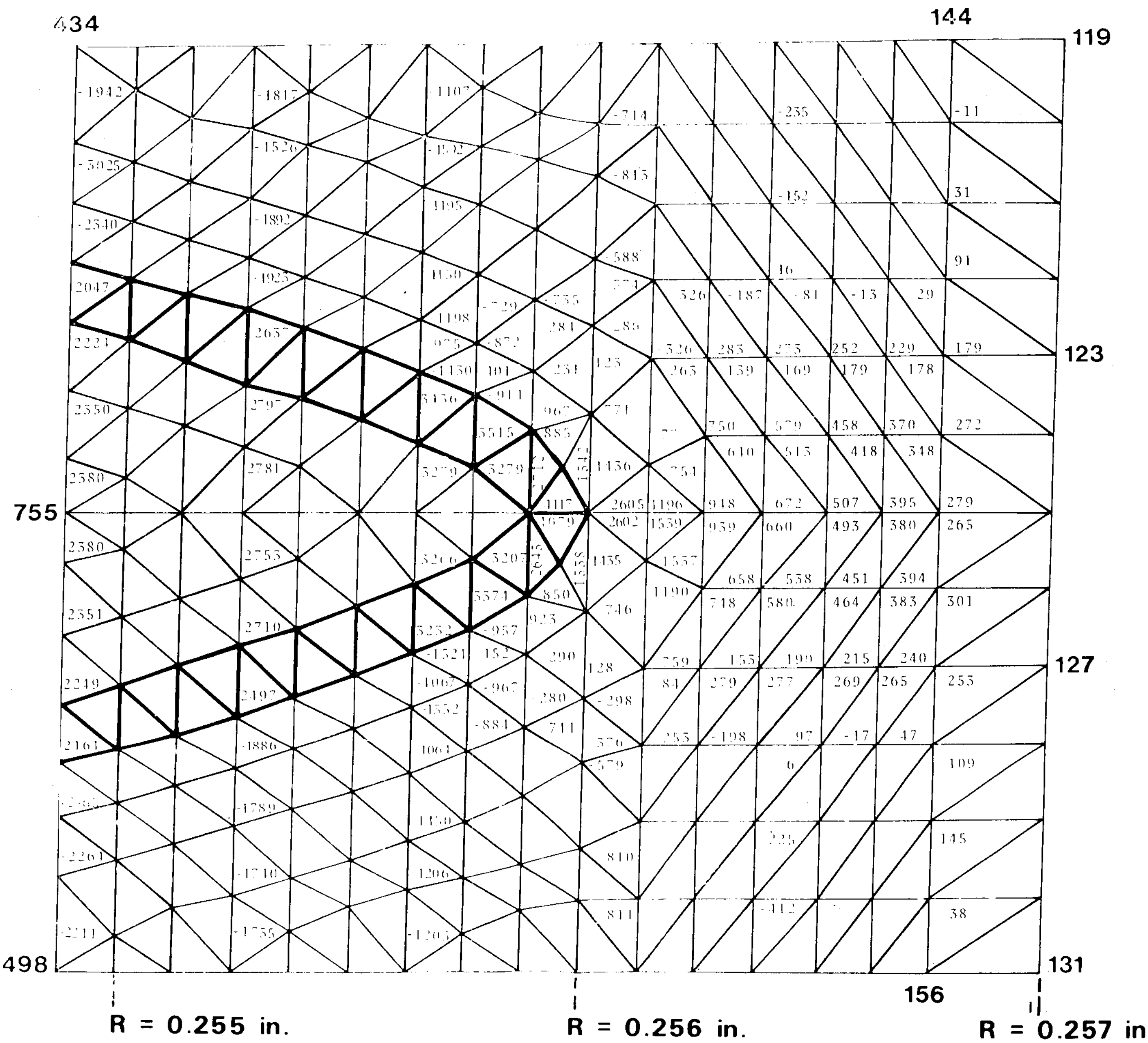


FIGURE 15. RADIAL STRESSES (PART 2C) IN PSI

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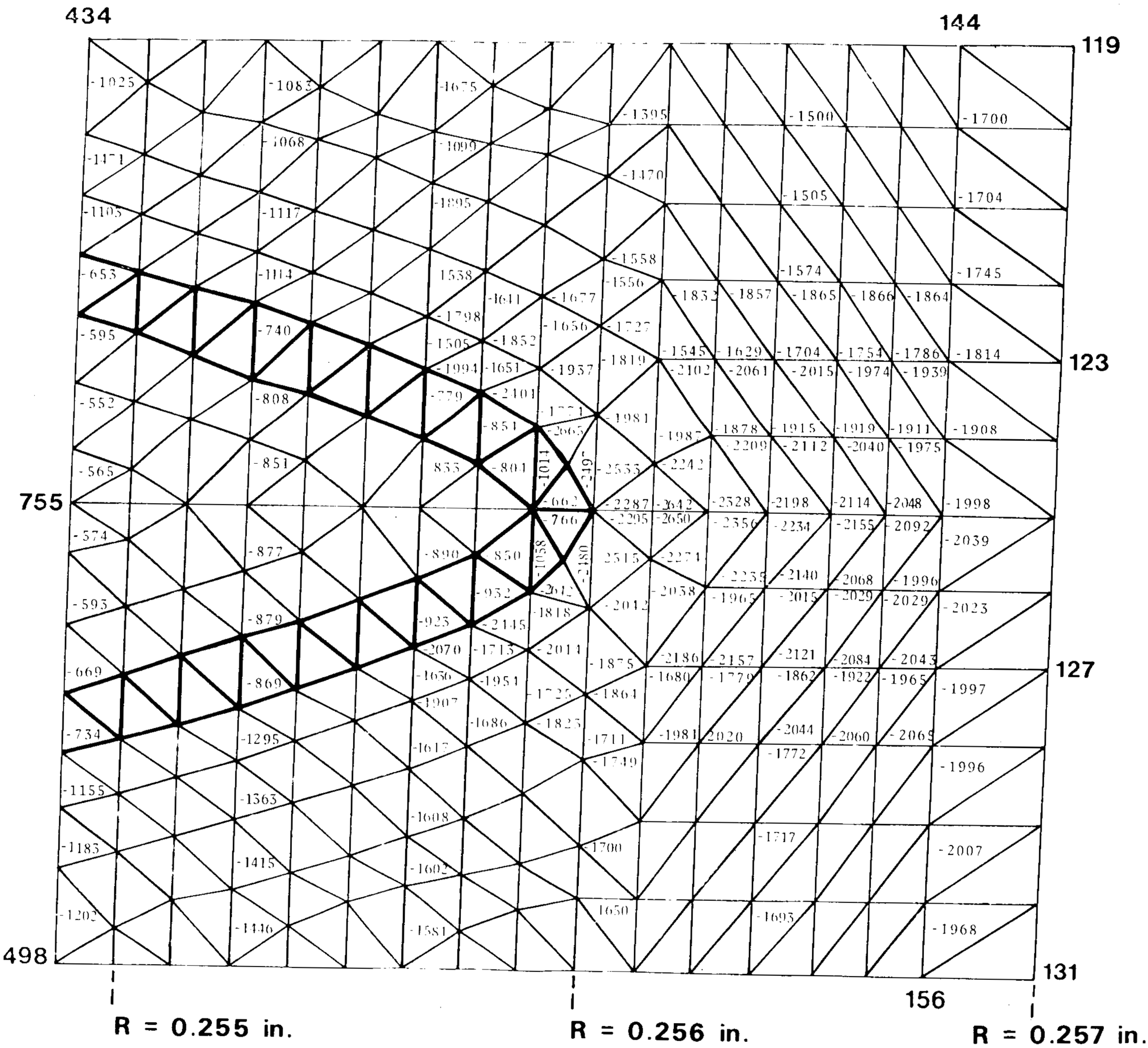

FIGURE 16. TANGENTIAL STRESSES (PART 2C) IN PSI

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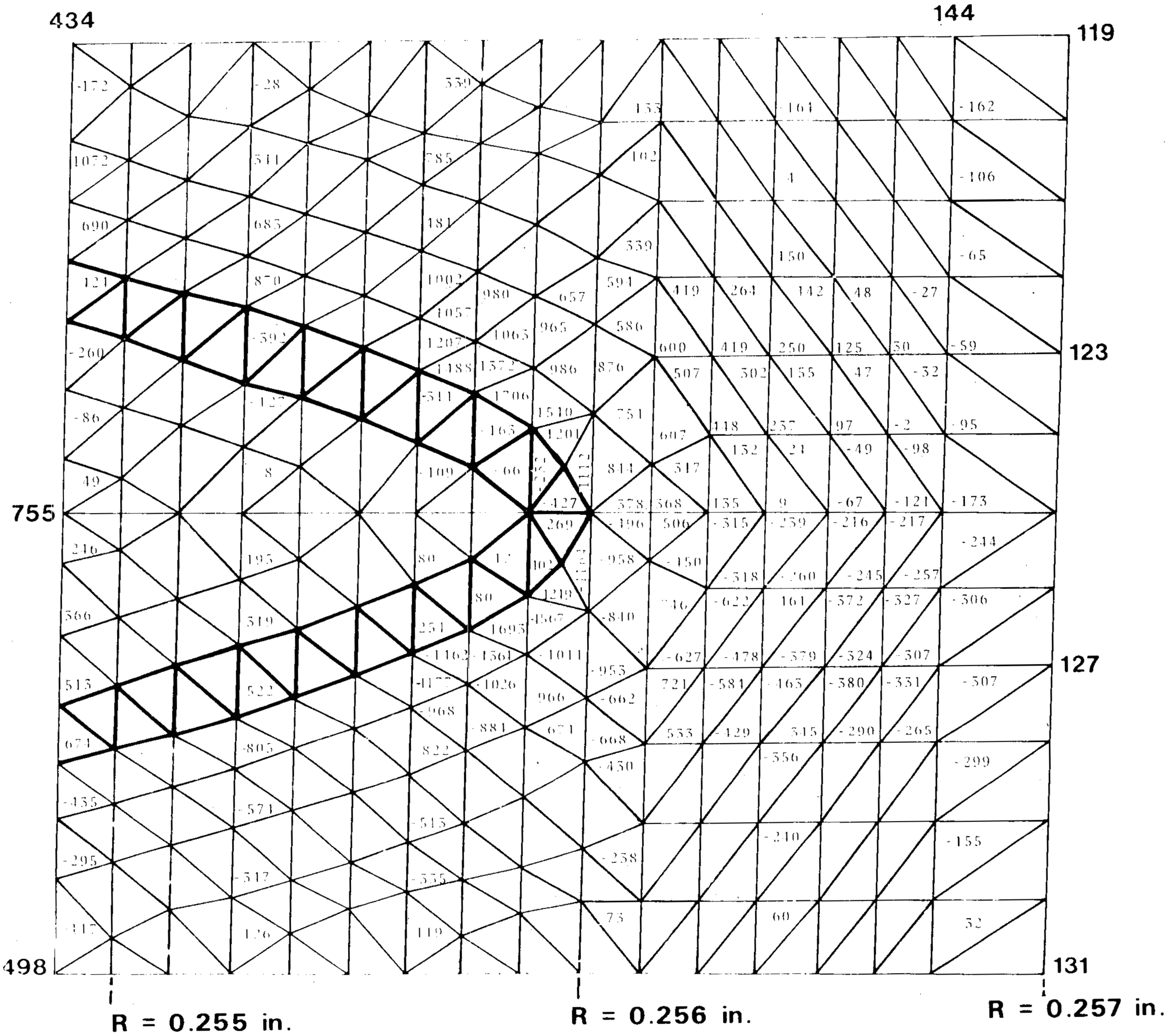

FIGURE 17. SHEARING STRESSES (PART 2C) IN PSI

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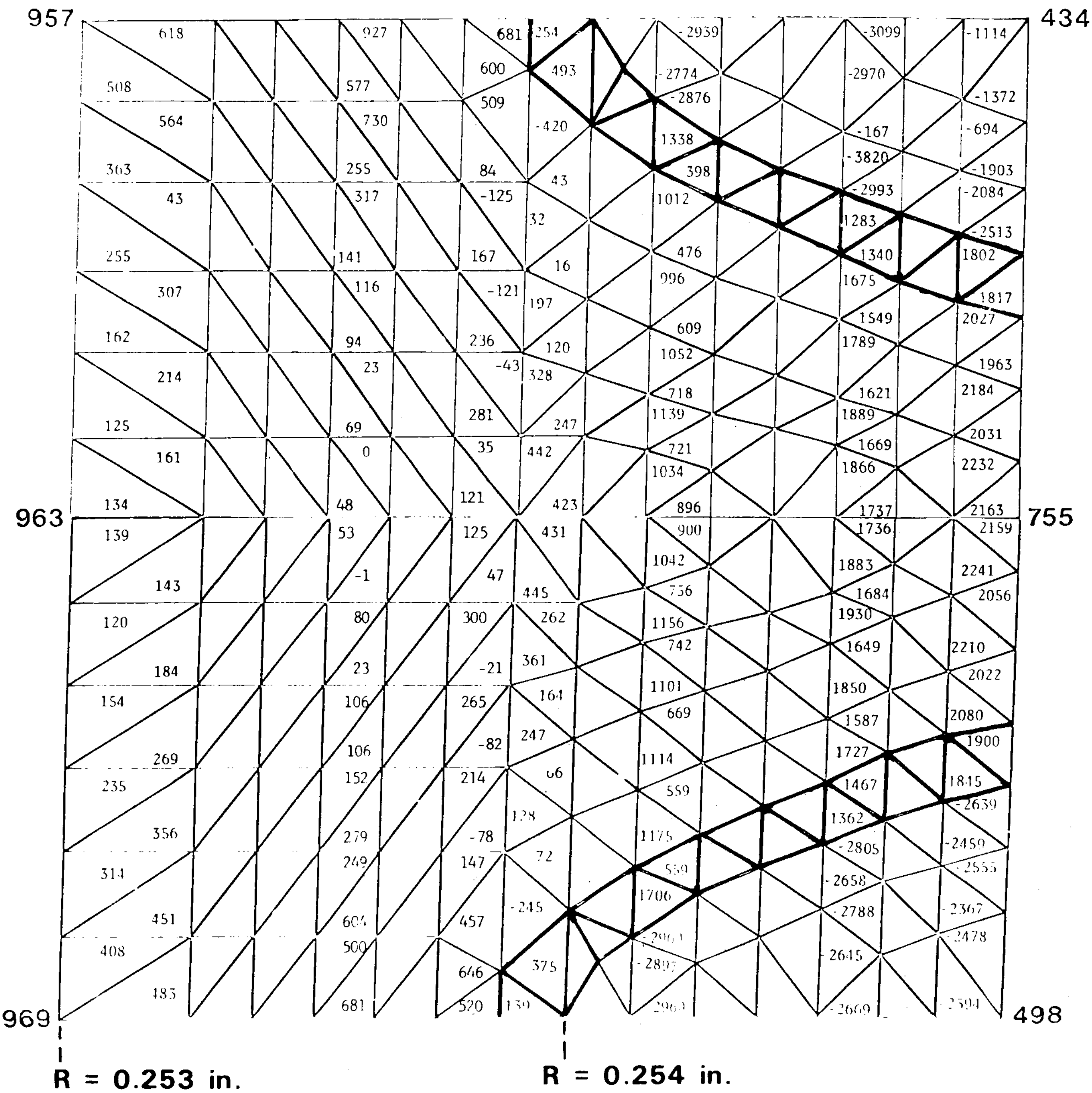

FIGURE 18. RADIAL STRESSES (PART 2D) IN PSI

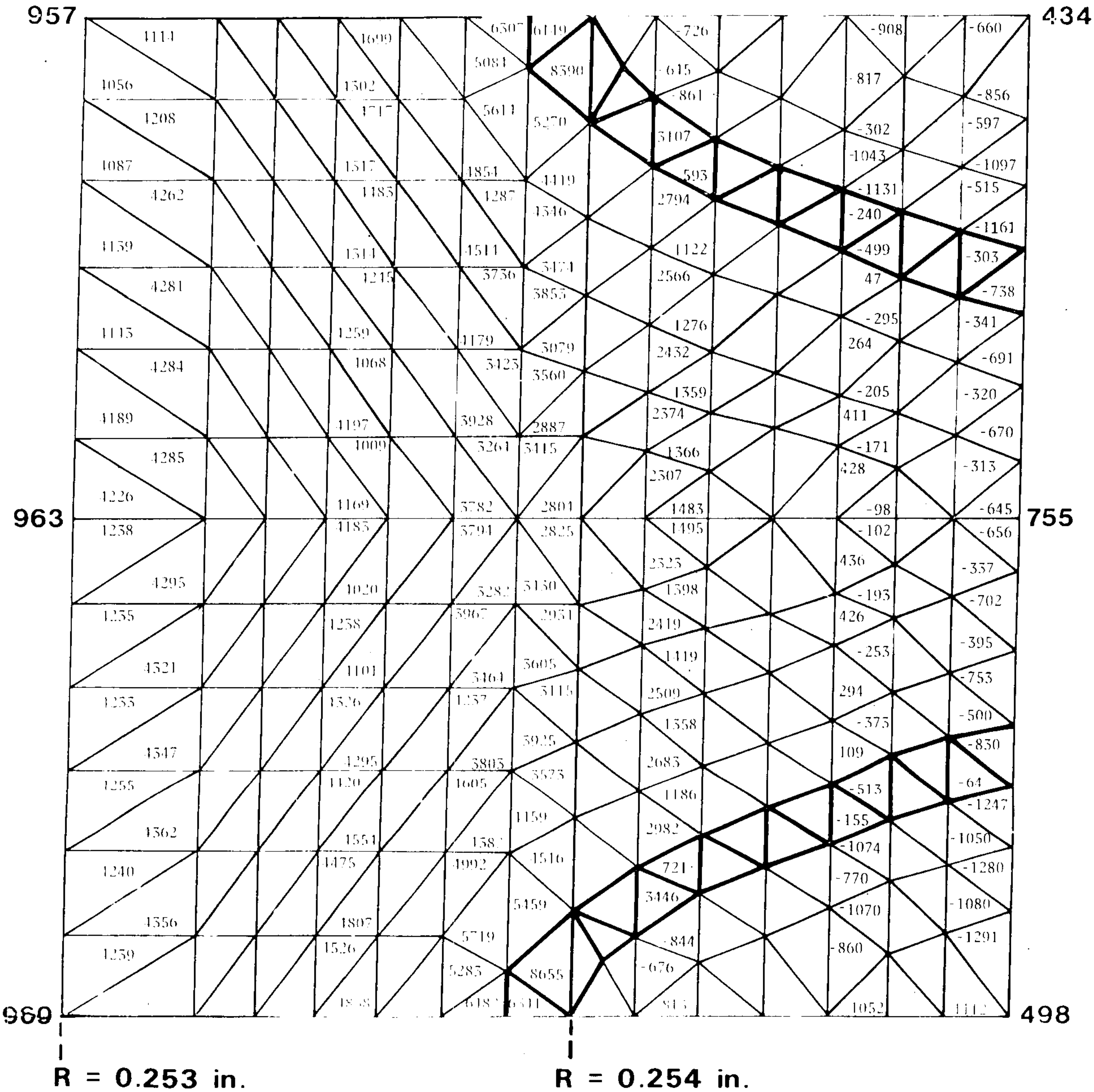

FIGURE 19. TANGENTIAL STRESSES (PART 2D) IN PSI

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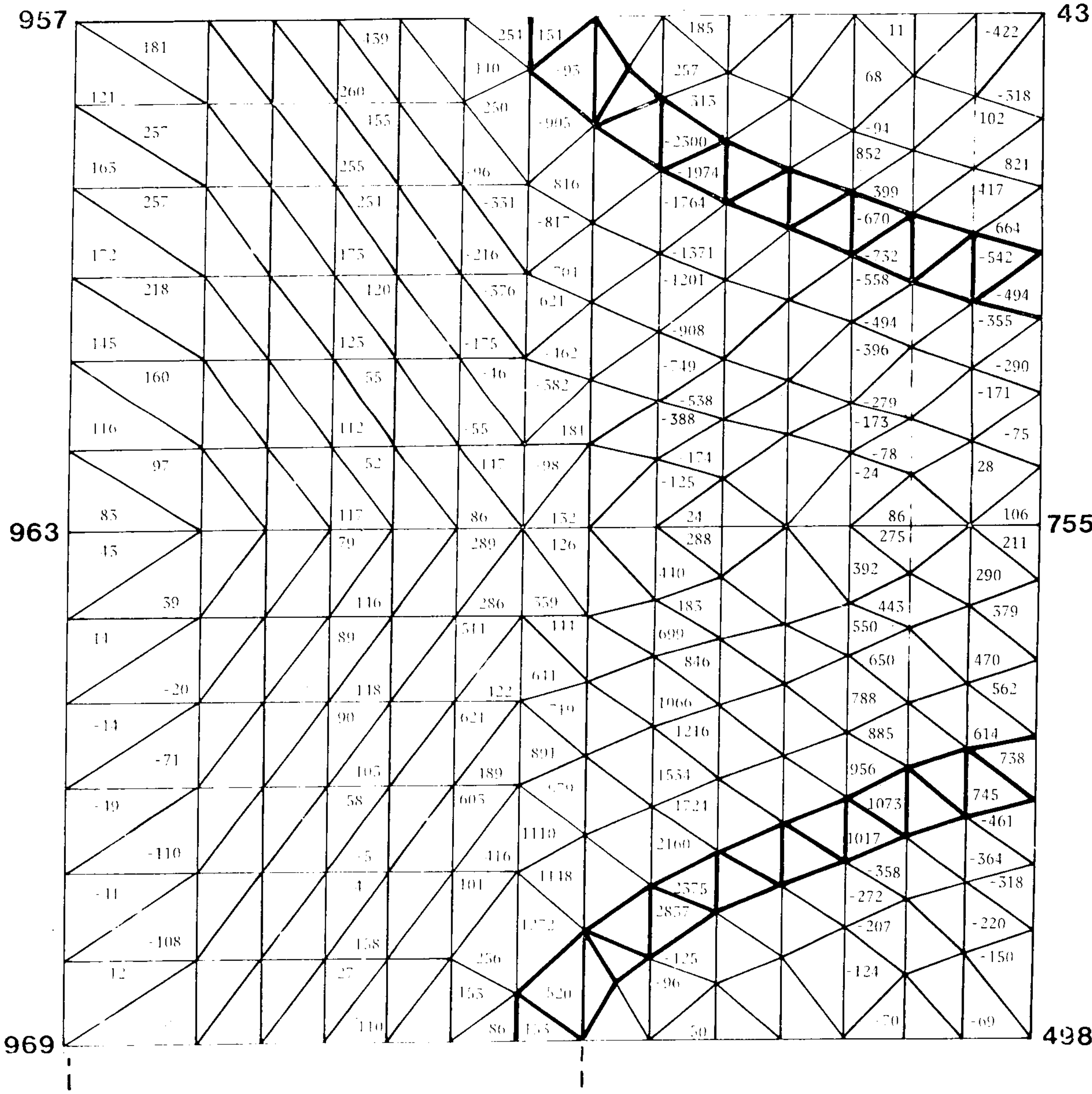

FIGURE 20. SHEARING STRESSES (PART 2D) IN PSI